

The Quali-Quantitative Structure of the City and the Residential Estate Market: Some Evidences

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Abstract. In the collective imagination there are masterminds speculating on real estate and so defining the "price of the buildings" in a sort of transposition in reality of *Hands over the city* plot. Although it is not the case, the distribution of prices in the contemporary city is a big deal for policy-makers and urban planners as well. Especially in metropolitan areas, where polarization of services is needed, the high complexity of urban scenarios makes the prediction of price variation due to change in the morphology or in the offer of services (for example in transportation and accessibility) very unreliable, despite of the success of policy and planning actions is strictly related to its control. This paper, moving in this perspective, points out some evidences on the relationships between the quali-quantitative structure of the city and the fluctuation of real estate prices with reference to house market, under the idea of investigating what is the role of urban railway stations.

As a matter of fact, railway stations are nodes of the transport network as well places of the urban environment whose big impact on accessibility in the city and the corresponding contribution in the definition of property values is very intuitive. The findings on the effects of railway stations on property values are mixed, since they vary on magnitude and direction.

This paper focuses on the comparison of the impact of urban railway stations on the residential estate property values as well on the structure of the city in itself, grasped in terms of configurational state. To this aim, the paper proposes a case study, evaluating how the correlation among configurational indexes and residential values distribution varies with and without the presence of the railway system.

The main findings of the work make to arise a marginal or negative impact of the railway system, so as to promote the idea that other factors dominates the change in local property values around railway stations. Finally, the authors proposes the integration of ontologies and configu-

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rational analysis to define a methodological framework able to explain the state of residential estate market.

1 Introduction

The distribution of housing prices in the city is a long lasting theme in urban planning, still actual in the light of crisis that has been affecting cities and urban areas in the last ten years. It is a widespread opinion that the lack in knowledge of the mechanisms behind the dynamics of house prices in the city affects decision and policy making, as well as urban planning choices. If the amount of literature in the field is impressive, there is not a definitive approach that seems to prevail and it leaded to large disagreement in results. The question have been traditionally approached from specific points of view, probably neglecting the needed comprehensive vision: site and real estate peculiarities as well as the human behavior have been modeled to give reproducible results in the frame of an objective environment more than to give reliable outcomes. As an instance, environmental psychology and social sciences proved that the simple optimization of variables don not completely characterize the human behavior [31], taking sometimes priority other elements that are related to the users/environment correlation.

In this context, dominates the hypothesis of monocentricity (Central Business District - CBD) [34], which proposes that market values essentially depend on the accessibility of a location to the most central areas. In this sense, an element of the city pertains the distribution of real estate prices only if it directly impacts on the accessibility or at least in so far as it contributes to define the related patterns. As a result, the real estate market is generally described by a large set of variables that are exogenous to the model of the city and it provokes misunderstanding and distortions [18].

In the last years, the configurational approach to the analysis of the city opened new perspective to the understanding of urban phenomena, assuming the primary role of the space. As a matter of fact, also price distribution has been interpreted recurring to configurational logic and it leaded to significant results raging from housing to office prices [13,16,18,33]. Under the configurational hypothesis, the CBD model is completely integrated into the model of the city, thus resulting in the primary use of endogenous variables.

Stressing the configurational logic, this paper will investigate on the relationship among railway network and accessibility in the distribution of house prices in the city. Since the system of railway connection directly affects the topological structure of urban areas, the analysis will be carried out evaluating the impact of such a network on the correlation among the distribution of house prices and configurational indexes, following a methodological approach described in the following section. Moreover, moving from the common idea that a railway plays in two different domains, which are the accessibility yet introduced (the topological impact of the railway as a network) and the urban form and other externalities (the impact of the railway as a set of stations on the urban area

where they lean), the paper will explore also the hypothesis of expanding the purely quantitative approach with a quali-quantitative approach based on the integration of ontology and configurational analysis [7,9,19]. This hypothesis will be discussed in the last section.

More in details, in Sect. 2 is provided an analysis and a brief discussion of scientific literature in the domain of interest; in Sect. 3 there is the description of the methodological approach proposed and its application on case study is presented in Sect. 4, as well discussed in Sect. 5 along with general conclusions.

2 Backgrounds

In this section we give a comprehensive overview of existing literature in our domain of interest, focusing on configurational analysis, railway stations and networks, and knowledge representation through ontologies as well.

2.1 The Configurational State of the City

Cities are complex entities that are not prone to be precisely defined, since they defy formal descriptions. It is mainly due to the large amount of variables involved in its dynamic as well as to the overlapping of many competing entities that seem to challenge to dominate its scene. Planners, urban thinkers and designers then have been always trying to simplify the nature of the city, in order to grasp the fundamental nuclei of the urbanity, letting to emphasize hierarchies rather then geometries, or separation of parts from whole as well.

In the last forty years, thanks to the impressive development of automated calculus, a new "urban science" have been developing, stressing the idea to model complexity in cities recurring to the science of complex networks. In the early 80', Bill Hillier pioneered the notion of Space Syntax [31], fostering the use of centrality to define the configurational state of cities and open spaces. Such an approach is based on the extension to the city of measures and algorithms developed in structural sociology some decades before [24], under the idea that a city is made of two main layer that could be read separately, but that work together [48]. In the Space Syntax view, a city is therefore a complex system that behind a physical structure, which is composed by building connected by public spaces (streets, squares, ...), has a social structure, which is made of a large set of activities related by interactions [48]. This is what we call the duality of the city, which feeds a long-lasting debate on what is the dominant dimension and whether they are connected or not. Space Syntax proposes a theoretical position where they are one thing, so as to rethink the city as a "unique entity" that could be considered under a "unique theory" of the city as a whole, assuming the urban open space as "*the common ground for physical and societal cities*" [48].

The dominant elements and dynamics of the city are therefore expressed by the so-called "configurational state" of the urban system, which is expressed by the analysis of the set of "*relations between all various spaces of a system*" [48].

Under this view, the urban layout is completely expressible by a purely topological network, modeling the open space and their mutual connections. Space Syntax rethinks also the way the urban network is built, proposing a "dual" process that leads to a graph where points represent open spaces (typically streets and squares), while edges stand for their connection [30,38]. On this graph, centrality measures could be performed, so as to provide urban elements of numeric values representing its position in many urban hierarchies that define the configurational state of the city, directly related to the urban phenomena. There are many "configurational indexes", each one attributable to a correspondent index in structural sociology [38], although Space Syntax is mainly pivoted on the so-called "Integration Index" and "Choice Index". The first one refers to the concept of closeness in graph theory [41], expressing the idea that is "central" a node that is topologically close to all other in the system. The second one is related to the betweenness centrality [24], under the idea that the centrality of a node pertains its potential to intercept fluxes on the net being on as many geodesics path between any pair of nodes on the graph.

Betweenness centrality index C^b [24] and closeness index C^c [41] of a point p_i on a network of n nodes are:

$$C^b = \sum_{i=1}^{n} \sum_{j>i}^{n} \left(\frac{g_{ij}(p_k)}{g_{ij}}\right)[24]; \qquad C^c = \frac{n-1}{\sum_{i=1}^{n} d(p_i, p_k)}[41]$$

where: $d(p_i, p_k)$ = the number of edges in the geodesic path that links p_i and p_k
g_{ij} = the number of geodesic paths that link p_i and p_k
$g_{ij}(p_k)$ = the number of geodesic paths that links p_i and p_k containing p_k

The role of space in the city is precisely defined by Space Syntax, since it relates the dynamics of urban environment to the rates of movement in the city, assuming the existence of the so-called "natural movement", which is the part entirely and only depending on the grid configuration [29]. It de facto assigns to the urban layout a generative role on urban phenomena, as well as a primary role as catalyst in urban dynamics, since activities located in the city amplify the movement rates, playing as multipliers, generating new movement. It is the so-called "movement economy" [29], which governs the what happens in the city and drive its evolution. For further information, in the city there are also non-configurational attractors, which generate movement rates regardless of the layout. They are generally related to the planned expansion or regeneration of the city and often lead to what we call "urban pathologies" [30].

2.2 Housing Market, Railway Stations and Configurational State

In order to evaluate the impact of railway stations on property values, many authors suggest to see the stations as nodes of the transport network and places in an urban area [5]. The first characteristic relates to accessibility, which generally has a positive effect. The latter, on the other hand, is connected to the externalities of the stations and could have negative or positive effects case by

case. In the last 15 years, many empirical studies are pivoted on this approach [17]. As a result, the accessibility effects of a railway station is modeled in terms of distance between houses and the station in itself, as well by considering the quality of the railway network system as a whole, so as to primarily account for reachable destinations and eventually for other qualities like the frequency of the services, the facilities and many others. In this view, higher the accessibility, more positive the effect of the railway station is expected to be on house prices.

The idea that land/house prices and accessibility are strictly related is long-standing, since it roots in the work of Von Thünen, who explained the difference in values of similar farmlands due to diversity in accessibility [49]. Basing on these assumptions, further economists proposed the so-called bid-rent theory, which is pivoted on the relationship among the willingness to pay of an agent and the location of the land, so as to create a gradient declining with distance from a central area, generally named as Central Business District (CBD) [2,50]. The bid-rent model de facto considers as critical for values formation the accessibility to the CBD and therefore the transportation costs to reach it. A location proximal to CBD is considered attractive since there activities trend to polarize so as to give added value.

Investments in transports control prices by limiting friction around the CBD and attract household near to the stations [23]. It is therefore expected that house prices decrease moving away from stations. CBD is therefore an element that is exogenous both to the city in itself and to the price model [13].

In the last years, other researcher proposed models that interpret the distance from the CBD as a local property of real estate directly deriving from its position in the urban structure, so as to make CBD to turn in an endogenous element. Many of that researches analyze the effect of global and local accessibility on office and housing prices recurring to Space Syntax in the frame of a hedonic model of real estate prices analysis. The results show a good predictive power in interpreting the log of the rent, relating it to integration and choice indexes [13,33]. In this view, the railway system is integrated in the topological structure of the city, providing connection between nodes of the urban graph associated to the railway stations in reality [25,26]. It implies that only accessibility provided by the railway is taken into account, while externalities are missing if they not affect the relational state of the city.

Generally, researchers refer to this kind of model as "quantitative" and consider them useful since they assure a sufficient level of simplification not so deeply affecting the capability to read and interpret urban phenomena. However, some formal element of the city seem to be very important to have a deep understanding of complex mechanism acting in the city.

2.3 Representing Urban Knowledge Through Ontologies

Understanding the space in the city is paramount to identify actions for its management, so identifying homogeneous contexts containing highly related and characterizing elements is a necessary task. Therefore, acquire deep knowledge on

a built environment is pivoted on the recognition of its peculiarities, interpreted in the context of their physical and cultural environment.

Conceptual misunderstandings and semantic vagueness should be face prior to define a reasonable and reliable description of "urban knowledge", starting by the definition of a shared formalized language. Among the new available techniques to address the issue, ontologies seek to create a shared representation of information. That is intrinsically independent of the information itself, so that it could be isolated, recovered, organized and integrated only depending on its content [40].

With reference to spatial knowledge, ontologies have been gaining momentum in the last fifteen years, since they are used to represent its properties, as well as to harmonize and inter-operate data from different sources [4,32]. Ontologies could be used also to represent the spatial meaning of a community in time, such as physical and cultural landscapes and to give a formal representation of any element of the city.

The most widespread and used approach to ontology starts from the *modeling view* of knowledge acquisition [14]. In this frame, the model relates knowledge to the behavior of a generalized agent (the problem-solving expertise) as well as to its own environment (the problem domain). This approach contrasts the *transfer view*, which consider a knowledge base to be something like a repository that stays in the mind of an expert. Under the modeling view, knowledge is therefore strictly related to the real world, and much less dependent on the way it is used.

Knowledge representation is a pillar of the knowledge engineering process as a whole, in the frame of AI research, although much more interest have been payed to the nature of reasoning, so as to generate a real dichotomy between reasoning and representation, which seems to pertain to the philosophical debate among epistemology and ontology. As defined by Nutter, epistemology is "the field of philosophy which deals with the nature and sources of knowledge" [36], while ontology is much more oriented to the organization of the world, independently form of the related knowledge in itself. As a result, an ontology is *"a formal and explicit specification of a shared conceptualization"* [27], where the term *conceptualization* is to be referred to the model of the reality where the concepts are defined; *explicit* is related to what kind of constrains and concepts are used; *formal* is connected to the "machine-readableness" of the ontology; *shared* relates to the spread consensus of the modeled knowledge. Many other definition of ontologies have been developed, stressing some concepts more then others. Neches proposes a definition providing also a methodological approach to define an ontology: a) identification of terms and their mutual relations; b) definition of arranging rules; c) definition of terms and relations connecting concepts together. Under this view, an ontology is made of the explicit terms as well as of all those that can be derived by the implementation of rules and properties, so as to be a set of "terms" and their mutual "relations" [35].

Three basic questions are directly related to the reading and interpretation of urban environment. The first refers to the context, since the city has several signifiers directly connected to the nature of the ontology. The second is semi-

otic, in order to discuss the city that is by nature made up of signs in the real world. The third is epistemological and refers to the meanings of the concepts related to the city as an entity. Each question reflects an operational procedure, since upon signifiers, signs and meanings are based almost all the representation sciences, each of them proposing a model of the reality to be analyzed and evaluated to conclude interventions in the reality. Moreover, they are mutually connected by the matter of fact that a sign generates models intervention, goals and values to which planners refers in the definition of meanings that, in turn, affect approaches and criteria of intervention, directly affecting reality. When this latter change, perhaps, also induces changes in meanings, which imply new signs and then a new representation of reality and so on. Simplifying and lowering the complexity of urban environment is therefore mandatory to properly manage and share a knowledge representation of the city, although it is not a easy task.

As reported by Eco, giving a meaning to a signifier includes denotative and connotative elements [21]. To "denote" an object refers to give it a meaning, so as to have a real-time communication, since there are not ideologies or metadiscussions involved. Conversely, if a meaning expresses an ideology (also potentially as well as in hidden way) it is connotative, and it is related to values, symbols and intangible cultural elements. Through forms it is therefore possible to recognize the relation among objects and societies, in diachronic perspective also, giving momentum to the preservation of traces and evidences. When an element in the city is recognized, it become a sign and should be interpreted, not only in reference to itself (i.e. by decomposition) but also in the frame of the spatial and cultural context it belongs to.

In this frame, acquire interest also a formal definition of the concept of relevance information. It could be split in *objective* (system-based) and *subjective* (human (user)-based) relevance classes [28,42]. The objective relevance is a topicality measure, since it pertains to the matching among query and retrieved resources. Diversely, human relevance refers to many criteria [3,37,45], also related to the user's intellectual interpretations of the concepts of *aboutness* and *appropriateness* of the information that is retrieved.

On the basis of such a background, this paper would investigate the role played by railway system in defining the values of house market, under the idea of first evaluating its impact as a network providing accessibility (the set of connections created by the railway system as a whole) and eventually proposing a framework to approach its impact as a set of urban element in surrounding places (railway stations). The approach will be therefore based on a two-step strategy. Firstly, the urban system will be modeled in two scenarios representing the city with and without the railway system. For each scenario the configurational state will be calculated by means of configurational indexes and therefore the correlation among them and house price values will be evaluated, making the impact of railway network to arise. Secondarily, if results of first-step analysis can not

clearly state the railway impact, a framework to integrate qualitative (connected to the concept of railway stations as places) and quantitative (connected to the impact of railway network on the configurational state of the city) analysis will be proposed, stressing the notion of ontology.

3 Methodology

In order to evaluate the effect induced by the railway system on the residential estate market, the changes in correlation among the distribution of Space Syntax Integration index and the distribution of residential estate values will be analyzed.

The configurational state of the urban system will be provided recurring to Space Syntax Segment Analysis [43,44], that is an operational technique directly derived from the one pioneered by Hillier and Hanson under the notion of *Axial Analysis* [30,31]. Both the techniques are structurally based upon the building of the so-called *dual network* [38], which proposes the fragmentation of freely accessible spaces into the minimal set of the largest convex spaces, the subsequent tracing of the visual lines connecting them in a system, and, finally, the creation of the urban graph by the inversion of lines into nodes and junction into edges. The process is completely automated into *DepthmapX*, a software by University College of London [46], as well into GIS add-on and plug-in based on DepthmapXnet [47].

The resulting urban graph could be analyzed in order to calculate configurational indexes. This work proposes the use of a tailor-made ArcGIS plug-in, developed to integrate Space Syntax techniques into ArcGIS software [22], using the interface of DepthmapXnet [47]. Configurational data are therefore stored as numerical attributes of urban nodes in the frame of a geographical database. It allows to perform comparative analysis based on the location in space of configurational data.

In the same GIS environment will be stored the data on residential market, in terms of homogeneous price areas, deduced from normalized registered transactions. Thanks to the capability of geo-processing tools of ArcGIS, market data will be pushed on configurational data by adding local properties to nodes (intersect tool), so as to achieve a integrated DB where exploratory analysis of correlation will be performed.

As a result, on the dataset of the nodes of the urban graphs could be performed statistical analysis in order to analyze the correlation among configurational indexes and residential prices. Recurring to multiple model of the city, leading to as much urban networks, the impact of railway system will be analyzed by comparing resulting correlation among the said variables in the two different scenarios (Fig. 1).

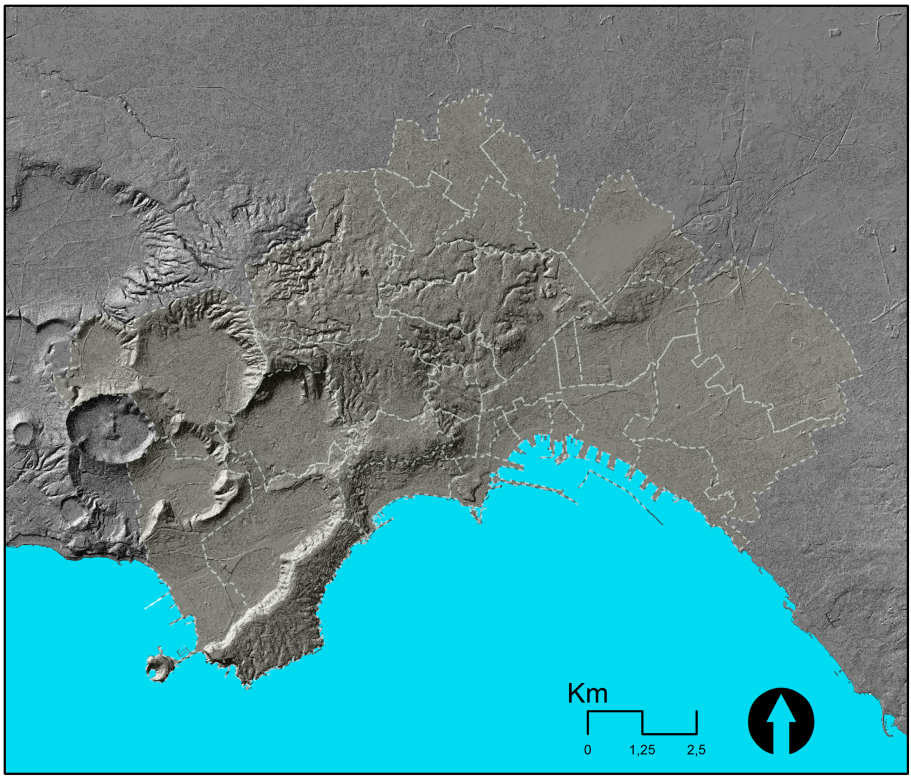

Fig. 1. Digital Terrain Model of the city of Naples. Yellow polygon in transparency highlight the boundary of the city. Dotted lines are the boundary of the administrative neighborhood. The DTM has been retrieved from the official geo-portal of Naples metropolitan city. (http://sit.cittametropolitana.na.it) (Color figure online)

4 Case Study

The proposed approach have been applied in the city of Naples, the third Italian city for magnitude of inhabitants and one of the largest of the Mediterranean basin at all. Despite the city has no more then one million people officially living into its boundaries, the surrounding urban area of the city has about 3.5 million inhabitants, so as to be the eighth urban area of the European Union. Since the territorial surface of the city is of 120 km^2, the population density is of 8.000 inhabitants/km^2, enclosed in a highly complex morphology, dominated along the east-west direction by the Mount Vesuvius and the Campi Flegrei Volcanic complex, two of the most active volcanoes in Europe. On the normal direction, the city is contained between the sea and a hill line that divide Naples from a large flatten area. Within the city, the morphology is based on two flat areas, divided by a higher hill line sloping toward the coastal line (Fig. 2).

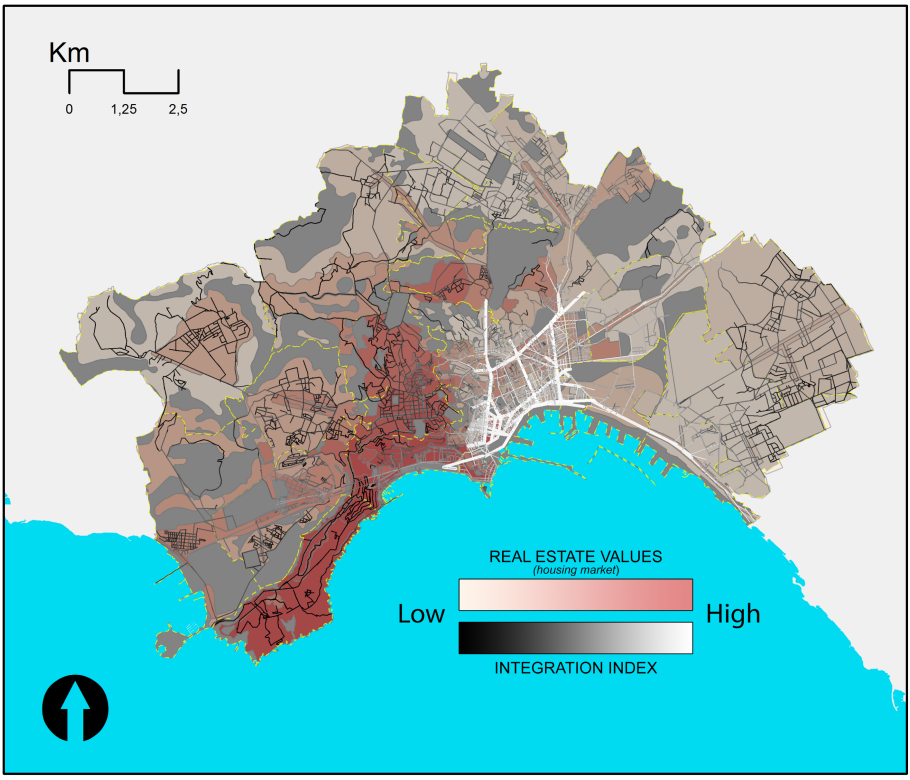

Fig. 2. The distribution of Integration index in SCN0 overlapped to homogeneous prices areas (red scale). Brighter the line, higher the index. Dark gray areas have no prices. Light gray areas are not included in the model, because they are outside of the city of Naples. (Color figure online)

As a result, Naples is a set of pseudo-autonomous area brought together by tunnels, so as to create a complex urban maze, with a long story of use and reuse, where narrow and chaotic spaces are close to neighborhood dominated by a ordered pace, as well as to large and planned boulevards resulting from the heavy urban changes of the nineteenth century. The configurational state of the urban system have been derived defining two different segment maps, in reference to a scenario composed only by the open spaces (SCN0) and a scenario implementing also the topological connection between lines due to the system of railway connections (SCN1). As described elsewhere [18,19], the configurational structure of Naples presents a set of critical lines where the highest values of integration and choice indexes polarize, so as to create what we call a central place. This kind of structure is almost the same in the two scenarios, although the distribution has significant local changes (Fig. 3).

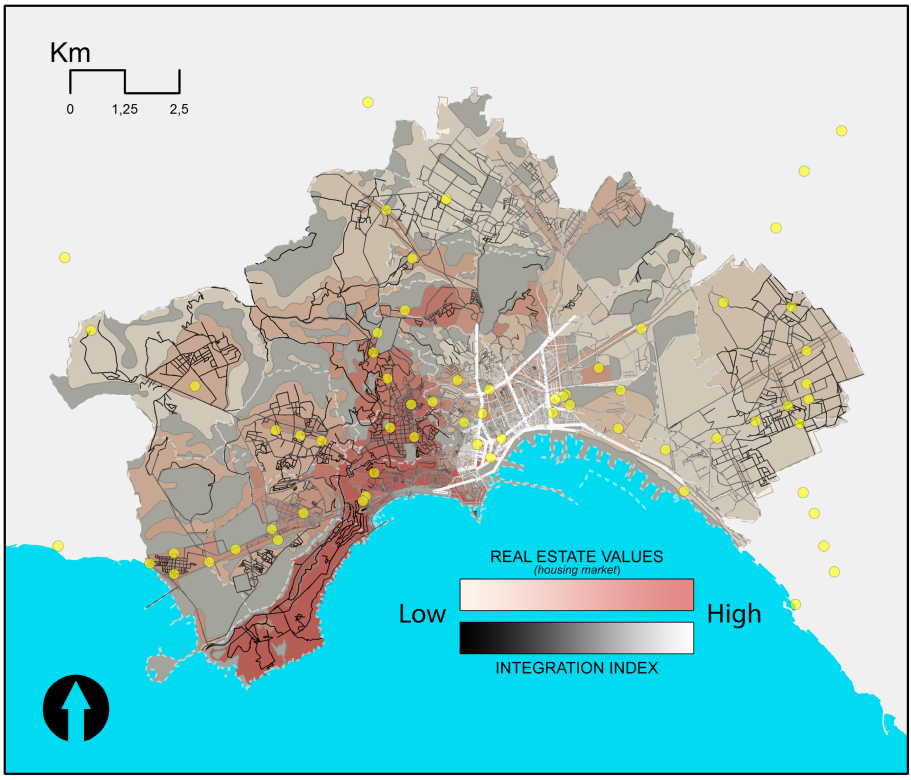

Fig. 3. The distribution of Integration index in SCN1 overlapped to homogeneous prices areas (red scale). Brighter the line, higher the index. Dark gray areas have no prices. Yellow points stand for railway stations. Light gray areas are not included in the model, because they are outside of the city of Naples. (Color figure online)

Recurring to the mapping clustering toolset, the hot spot area registering the higher values of the integration index (the so-called *integration core*) have been defined for SCN0 and SCN1. Figure 4 highlights the differences among them, giving emphasis to the topological effects of the railway system that reinforce the polarization of the integration core.

The residential estate market have been extracted by the official price list of Naples real estate exchange, base on a set of 3402 normalized transactions that have been registered in the 2011 second semester [6]. Using the geospatial tool of GIS environment, the prices have been pushed on the configurational segment, letting to integrate attributes on a singular feature. It leads to perform agile correlation analysis by the implementation of exploratory algorithm. More

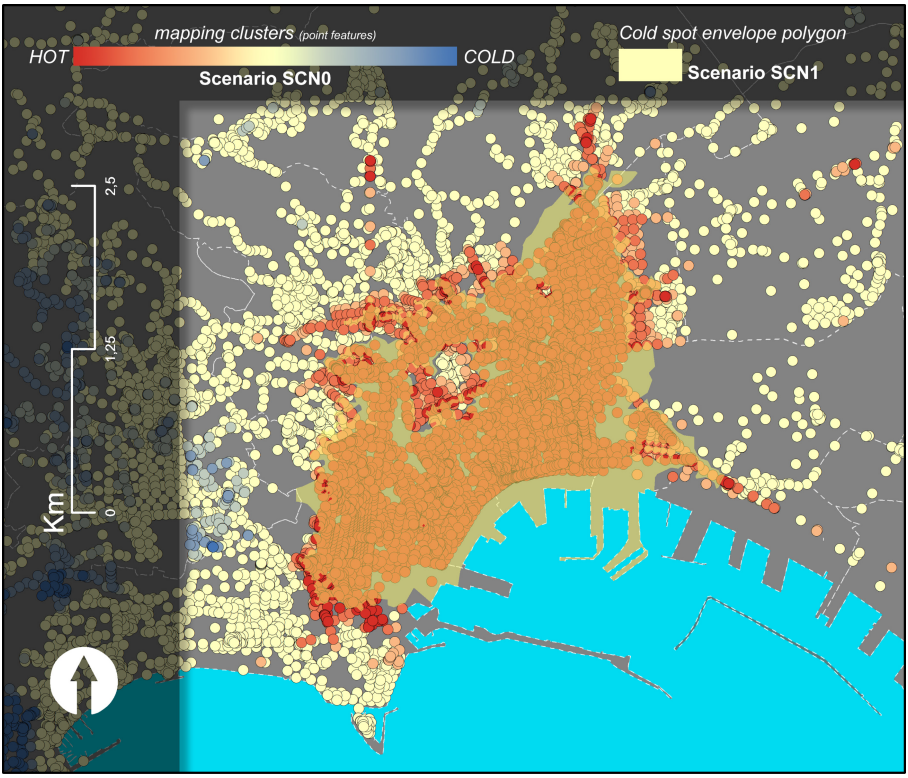

Fig. 4. The envelope polygon of Integration index's cold spots in SCN1 overlapped to the cluster map of Integration index in SCN0. Red dots exceeding the yellow polygon in transparency highlight the higher polarization of the Integration index in SCN1. (Color figure online)

specifically, the residential estate values have been correlated with the three configurational indexes of Integration, Choiche and local integration (400 m radius) [30].

As a result, a correlation matrix has been obtained for the two scenarios so as to let the measure of the impact of railways on such relations. Figure 5 summarizes the change in correlation among the said variables in terms of histogram. Vertical lines above x-axis mean better correlation, while those below mean weaker and the absence of any line means that any change in correlation has been induced. For the largest part of the neighborhoods the correlation is weaker.

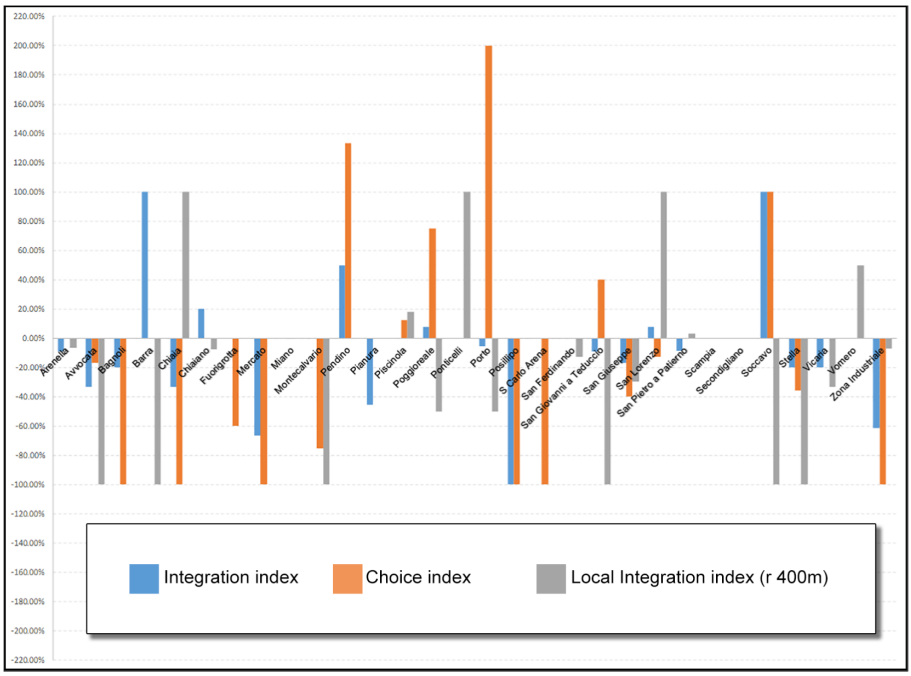

Fig. 5. Histogram summarizing how the correlation among Integration index, Choice index, local Integration index (r 400 m) and housing prices change with the inclusion of the railway system in the configurational model of Naples (y-axis displays the change in correlation expressed as percentage on the original values: if the correlation doubles, the correspondent value on the y-axis is 200%). The graph clearly states that a general lowering is induced.

5 Discussion of Results and Conclusions

The correlation among configurational indexes and housing prices in Naples lowers in reliability if the network model of the city is provided by the set of connections due to the urban railway system. In the view of the authors, it could have at least two different explanations. A first could be an insignificant role of the urban railway system on the effectiveness of accessibility of the city, which, in turn, does not affect the housing prices. Such a possible explanation is however unrealistic for two main reasons. First of all, scientific literature states that almost everywhere railway stations deeply affect the local market, causing a generalized increase in prices with a gradient similar to the CBD logic. Secondarily, only the two most important urban railway routes of Naples (Linea 1 and Linea 2) let 173.146 movements per day [1], which are the 22% of the car movement per day [15] (dominating movement mode in the city).

Such considerations let the authors to get a second explanation to the discussed lowering in the correlation, which refers to the incapability of a purely

configurational approach to grasp the nature of the housing market. This latter seems to depend from multiple factors raging from objective (i.e. configurational) to subjective features. Generally speaking, the phenomenon seems to depict the dispute between accessibility and externalities, making the impact of combining benefits and nuisances to arise on real estate values distribution.

Such a complex matter therefore needs to be approached trough an integrated solution, able to formally define both kind of knowledge (objective and subjective). As preliminary proposed elsewhere [9–11,20], a local urban element that is formally defined by a proper ontology (i.e. [12]) in its subjective properties, as well by configurational indexes in its objective qualities, in the frame of an urban environment, could be described by means of the so-called Configurational Ontology [9] as:

$$CO = O(C^c, C^b) \tag{1}$$

where O is the ontology as represented in our model, and C^x are the following network point centrality measures [24]:

$$C^c = \frac{n-1}{\sum_{i=1}^{n} d(p_i, p_k)}; \qquad C^b = \sum_{i=1}^{n} \sum_{j>i}^{n} \left(\frac{g_{ij}(p_k)}{g_{ij}}\right)$$

where:

$d(p_i, p_k)$ = the number of edges in the geodesic path that links p_i and p_k

g_{ij} = the number of geodesic paths that link p_i and p_k

$g_{ij}(p_k)$ = the number of geodesic paths that link p_i andp_k containing p_k

The configurational indexes $C^x$are attributes of the Configurational Ontology, and they are strictly related to the configurational indexes of Integration (closeness centrality) and Choice (betweenness centrality), as introduced in Sect. 2.

Such an approach combine centrality measures quantitatively influenced by the meaning of urban elements, understood as "local properties" on the nodes composing the city network.

The authors proposes to develop and use such an approach to provide an integrated quali-quantitative knowledge about the city so as to have a clearer view of the relationship among formal properties of the city, its configurational state, and the distribution of housing market values. Under this view, accessibility provided by the railway network and the externalities locally provided by railway stations could be effectively taken into account.

Since the approach is based on the definition of an appropriate ontology of the city, the future developments need to go firstly into that direction, in order to reach an adequate formal description of the city that should be comprehensive of urban element relevant at the scale of the city as a whole as well of their mutual relationships taking into account efficient technique to integrate domain knowledge [8,39].

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